Biological Conservation 227 (2018) 259–265

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

The cost of enforcing a marine protected area to achieve ecological targets for the recovery of fish biomass

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ARTICLE INFO

Keywords:
Marine reserve
Fisheries
Poaching
Conservation planning
Coral reef
Ecological impact evaluation

ABSTRACT

Protected areas are the primary management tool for conserving ecosystems, yet their intended outcomes may often be compromised by poaching. Consequently, many protected areas are ineffective 'paper parks' that contribute little towards conserving ecosystems. Poaching can be prevented through enforcement and engaging with community members so they support protected areas. It is not clear how much needs to be spent on enforcement and engagement to ensure they are frequent enough to be effective at conserving biodiversity. We develop models of enforcement against illegal fishing in marine protected areas. We apply the models to data on fishing rates and fish biomass from a marine protected area in Raja Ampat, Indonesia and explore how frequent enforcement patrols need to be to achieve targets for coral reef fish biomass. Achieving pristine levels of reef fish biomass required almost year-round enforcement of the protected area. Surveillance of the protected area may also be enhanced if local fishers who support the reserve report on poaching. The opportunity for local fishing boats to participate in surveillance was too small for it to have much benefit for total reef fish biomass, which increases slowly. However, specific functional groups of fish have much higher population growth rates and their biomass was predicted to increase markedly with community surveillance. We conclude that budgets for park management must balance the cost of conducting frequent patrols against supporting alternative activities, like education to build community support. Optimized budgets will be much more likely to achieve ecological targets for recovering fish biomasses and will contribute to fiscal sustainability of protected areas.

1. Introduction

Protected areas are a primary tool for conserving ecosystems. Protected areas are often used to protect marine species from the effects of fishery exploitation, which reduce the biomass and diversity of species (Edgar et al., 2014). Recent international commitments to meeting Convention on Biodiversity targets have seen rapid growth in marine protected areas globally, with coverage increasing more than four times since 2000 (Watson et al., 2014; Boonzaier and Pauly, 2016). However, many of these new protected area may be 'paper parks' that are not enforced (Gill et al., 2017). Globally, the marine protected areas with the highest biomasses and diversity of large fish are those that are old, large, fully protected from fishing, isolated and well enforced (Edgar et al., 2014).

Ensuring that protected areas deliver their intended conservation outcomes requires sufficient ongoing funding for enforcement and for building community support (Gill et al., 2017). The expense of enforcing protected areas may be a major impediment to their long-term success (Ban et al., 2011). Poaching in protected areas can erode their benefits for conserving biodiversity (Bergseth et al., 2015; Rizzari et al., 2015). Poaching may occur when poachers perceive the probability of detection is low and/or if the park's objectives lack community support (Arias and Sutton, 2013; Bergseth et al., 2017). Patrols of protected areas are critical to maintain compliance (Kelaher et al., 2015), but often budgets for patrols are not sufficiently resourced and patrols are not comprehensive enough to maintain compliance. Community

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https://doi.org/10.1016/j.biocon.2018.09.021
Received 29 January 2018; Received in revised form 27 August 2018; Accepted 17 September 2018
0006-3207/

support is also critical, so that fishers avoid poaching and report offenders. Community support can be achieved through engagement activities, such as education and consultation with communities on management plans (Leisher et al., 2012). However, the connection between expenditure on enforcement and the benefits of protection are generally not considered during the design stage, where the expectation around benefits typically involves an implicit assumption of perfect compliance (Davis et al., 2015). Numerous studies have addressed the opportunity costs of marine protected areas for fishing (e.g. Smith et al., 2010). What has not been addressed is how much needs to be spent on enforcing reserves so that fish biomasses are sufficient to conserve their ecological functions. Further, budgets for enforcement and community engagement are typically allocated ad-hoc, but budget allocations may be more effective if we could value community support in terms of avoided cost of patrols (Fox et al., 2017).

Here we develop an analytical framework for estimating the cost of enforcing protected areas so that fish biomass meets conservation targets. We estimate the cost of achieving specific biomass targets, including ecological relevant targets for fish biomass, where cost is given in general terms of days of patrols required. We apply the framework to model the Kofiau and Boo Islands Marine Protected Area in Raja Ampat Indonesia (Ahmadia et al., 2015). Raja Ampat is the global center of coral and fish diversity, but faces considerable pressure from fisheries. Efforts over the past ten years to establish protected areas have been successful and now management is transitioning to fiscal sustainability, thus quantifying budgetary needs for effective management is timely.

2. Methods

First we describe a model of fish biomass inside protected areas, when the fish population is subject to variable levels of poaching. Then we describe application of the model to the case-study in Raja Ampat.

2.1. Models of poaching, enforcement and compliance

We modeled poaching as a discrete and intermittent event, rather than using the traditional approach of modeling fishing mortality as a continuous pressure. Poaching events may often be intermittent, because poachers are fishing intensively for small amounts of time in an attempt to avoid enforcement officials. For instance, reefs in Indonesia are subject to fishing by ‘roving bandits’, commercial scale vessels that roam large areas and intensively fish local areas for relatively short-periods of time (often with illegal fishing gear), before they move to the next reef (Berkes et al., 2006). Small-scale poachers may also fish intermittently, for instance poaching by recreational fishers in the Great Barrier Reef marine protected area is most likely to occur on public holidays (Bergseth et al., 2017).

We developed two complementary models of poaching, which represent alternative plausible poaching behaviors. In both models we assumed fish growth was logistic with fixed parameters r (intrinsic growth rate) and K (maximal biomass), and that poaching occurred at random intervals where the mean interval time d was described by an exponential distribution with rate $u_z = 1/d$. Thus, the equilibrium state for both of these models was a distribution of fish biomass.

The probability of a given biomass was calculated slightly differently for each model. In the first model, a poaching event ends once fish biomass has been depleted to a fixed level, B_O (Fig. 1A). Fishing would deplete biomass to a fixed level if the marginal cost of harvesting fish increases as density in the reserve is depleted (e.g. White et al., 2008). Once costs exceed the expected revenue generated from poaching a reserve, a roving poacher will move elsewhere. This model had an analytical solution for the probability of different fish biomass levels (Possingham, 1989), Fig. 1B). Taking the above assumptions for Model 1, we can calculate the probability of observing fish biomass B_{Obs} at a random sampling time greater than or equal to a pre-specified level (B_Q) as:

$$pr(B_{Obs} \geq B_Q) = 1 - e^{-u_z t_z} \tag{1}$$

where t_z is defined by the solution to the logistic growth function:

$$t_z = \frac{\ln(B_{Obs}K - B_{Obs}B_0) - \ln(KB_0 - B_{Obs}B_0)}{r} \tag{2}$$

In the second model we assumed poaching mortality occurred at a fixed rate. This model was defined by the difference equation:

$$B_{t+1} - B_t = B_t r\left(1 - {}^{B_t}\!/_{K}\right) - FB_t x_t, \quad with\ x_t \sim bern(u_z) \tag{3}$$

$$with\ x_t \in \{0, 1\}$$

where F is the fixed poaching rate and x_t is an indicator variable for whether poaching happened or not, and is drawn from a Bernoulli distribution with probability u_z. Interval times between poaching events will follow an exponential distribution, as for model one. The mean poaching rate is Fu_z and in the limit when $u_z = 1$ this model reverts to the difference form of the logistic model with a continuous harvest rate. Because the biomass after depletion in Model 2 depended on when poaching started, we used simulations to determine the distribution of fish biomass. Simulations were run for 500 years on a daily time-step to ensure the distribution of fish biomass had converged on its equilibrium state.

Our next aim was to determine how enforcement affected the distribution of fish biomass. In both models, enforcement increased the average time interval between poaching events, such that enforcement patrols decreased the rate of poaching in proportion to the number of days per year that were patrolled:

$$u_z = u_{base} - bu_{base}\frac{d}{y} \tag{4}$$

where u_{base} was the poaching rate with no enforcement, d is the annual number of days that were patrolled, y is units per year (e.g. days = 365) and b is a parameter controlling how sensitive poachers are to enforcement. If $b = 1$ then poachers reduce their rate of poaching in proportion to the amount of enforcement. If $b < 1$ poachers are less sensitive to the rate of enforcement patrols. This may occur if poachers do not know of the park's existence, are able to avoid detection, or penalties are insufficient (Byers and Noonburg, 2007). If poachers are risk averse then $b > 1$ and the rate of poaching decreases faster than the rate of enforcement.

Community support for a park may also increase the days patrolled, if community members engage in surveillance. Therefore, the final term in Eq. (4) for the proportion of days patrolled becomes:

$$\frac{d_{new}}{y} = \frac{d + c}{y} - \frac{dc}{y^2} \tag{5}$$

where d is the number of enforcement patrols per year and c is the number of days per year that community members are likely to report poachers if they encounter them. The model assumes community visits and patrols are independent and the term dc/y^2 accounts for days when community visits and patrols co-occur.

2.2. Application of the models to Raja Ampat marine protected areas

We applied the enforcement models to estimate the number of patrols per year required to achieve biomass targets for reef fish biomass in the Kofiau and Boo Island Marine Protected Area, Raja Ampat, Indonesia (Fig. 2). Initially we presented results from a base-case, then we conducted further analyses to explore how the spatial and biological context of a reserve may affect the required rate of patrols. Our objective in these analyses was to explore the effect of different assumptions and contexts on the days patrolled, so we focus on comparing different scenarios and do not provide precise error estimates for days patrolled.

In the base case we derived parameters for the models to represent